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Final Report
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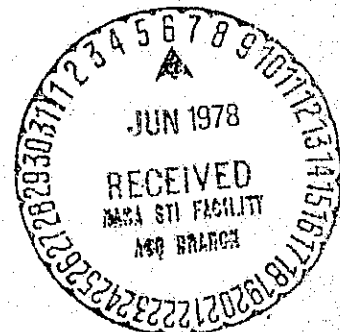
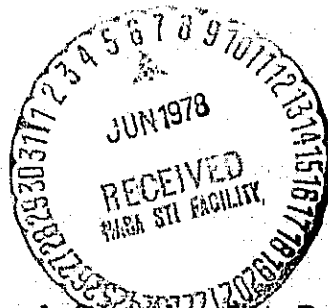
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1 January 1978



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ABSTRACT

The results of a quasi-optical mixer improvement study are presented in this report. A mechanically stable single block mixer design is described utilizing a recessed whisker and beamwidth equalization lens. A stripline I.F. matching section which is an integral part of the mixer is presented. Engineering measurements of wire grids and dielectric transmission loss near one millimeter wavelength are given and an anomolous I-V curve behavior observed during diode whiskering is discussed.

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1.0 INTRODUCTION AND SUMMARY OF RESULTS

The following report describes the results of a four man-month study to improve the stability of a non-waveguide quasi-optical Schottky barrier diode mount undertaken to make the mount suitable for use in flight applications. The study is an integral part of a general effort at JPL to develop receivers in the range from 200 to 1000 Ghz. The quasi-optical mixer was developed earlier in the general program (1) and the performance characteristics of several laboratory bread-board versions of the mixer were tested at various frequencies up into the submillimeter band (2). This report describes a number of improvements made in the mixer design and also presents some engineering information obtained in the mixer development study.

Section 2 deals with the specifics of the improved mixer. The objectives of the study were to provide: 1) Increased mechanical stability of the mount. 2) Stability and reproducibility of the whisker. 3) Equalization of E and H plane mixer beamwidths. 4) Integral mixer I.F. matching and D.C. blocking. As described in Section 2.0, Mechanical stability of the mount was achieved by a single aluminum mixer block construction. Whisker stabilization was achieved by a new recessed whisker design described in Section 2.1. The E and H plane beamwidths of the mixer were equalized by means of a small lens discussed in Section 2.2. Section 2.3 describes the stripline I.F. matching section which was built directly into the mixer block.

Engineering measurements of a number of material properties are given in Section 3.0. Measurements of the reflectivity of wire grid meshes at 250 Ghz are presented in Section 3.1 to provide information for the construction of resonators and beam splitters. Measured transmission loss of a number of dielectric materials at 300 Ghz are given in Section 3.2, and it is determined that Teflon is one of the better engineering materials at this frequency.

Finally, Section 4.0 describes an anomolous "burn-in" effect repeatedly observed in the diode I-V characteristic while the whisker contract to the chip is being made.

2.0 THE IMPROVED MIXER

A number of improvements were made on the quasi-optical mixer described in reference (1) in order to make it suitable for flight applications. These improvements were mainly directed towards increasing the stability of the mixer since the first experimental units often failed under mechanical vibration and temperature cycling. A photo of a 200 Ghz version of the improved design is shown in Fig. 1. The mixer is formed from a single block of aluminum in an attempt to form the most mechanically stable structure possible. The basic internal structure of the mixer is as described in reference (1). However, the new mixer has an internal I.F. matching section, a recessed whisker and a beamwidth equalization lens. These aspects of the mixer are described in detail in the following sections. The mixer in Fig. 1 was designed to fit into a quasi-optical local oscillator injection system with the semi-circular output face registering directly against the flat face of a teflon collimating lens.

The lower bullet which mounts the whisker is made of brass and is pushed into a hole reamed in the bottom of the mixer block. The bottom of the bullet can be seen in the center of the mixer. The spherical mixer back short is machined directly into the aluminum block by means of a tool which is inserted through the lower bullet mounting hole.

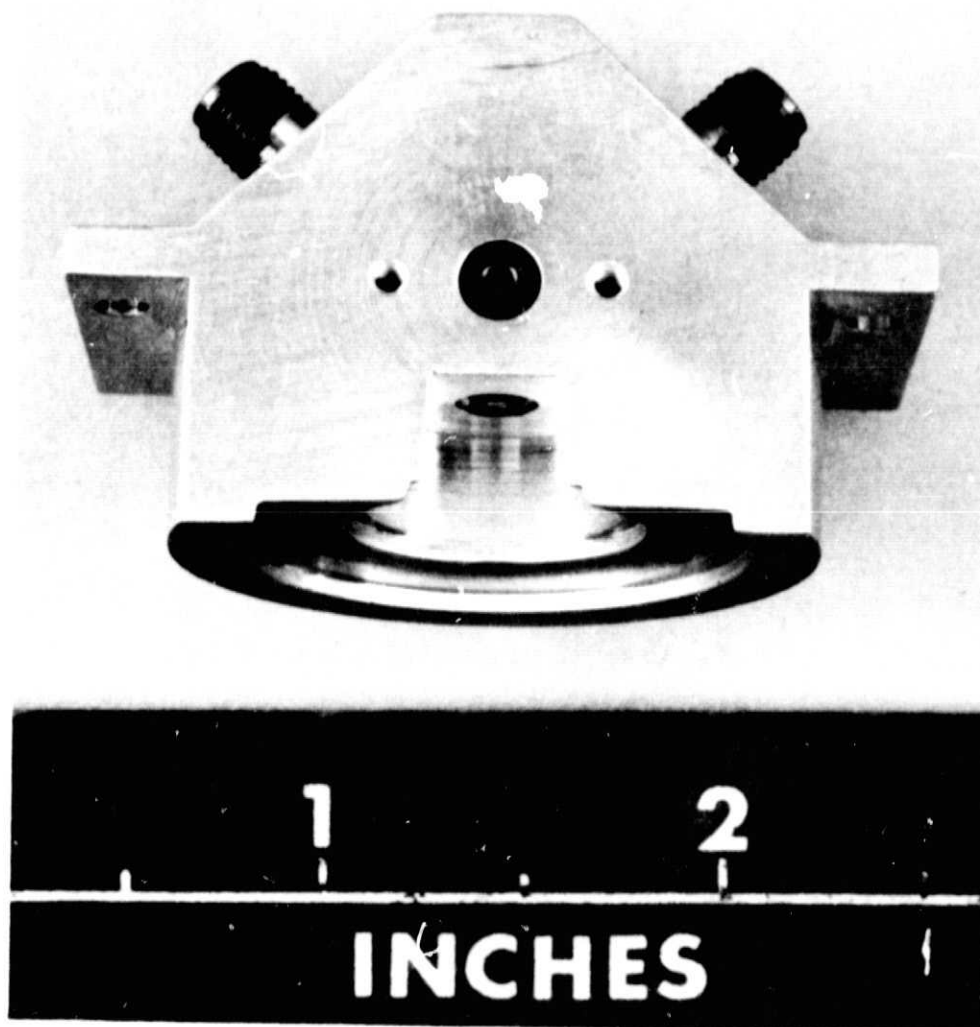


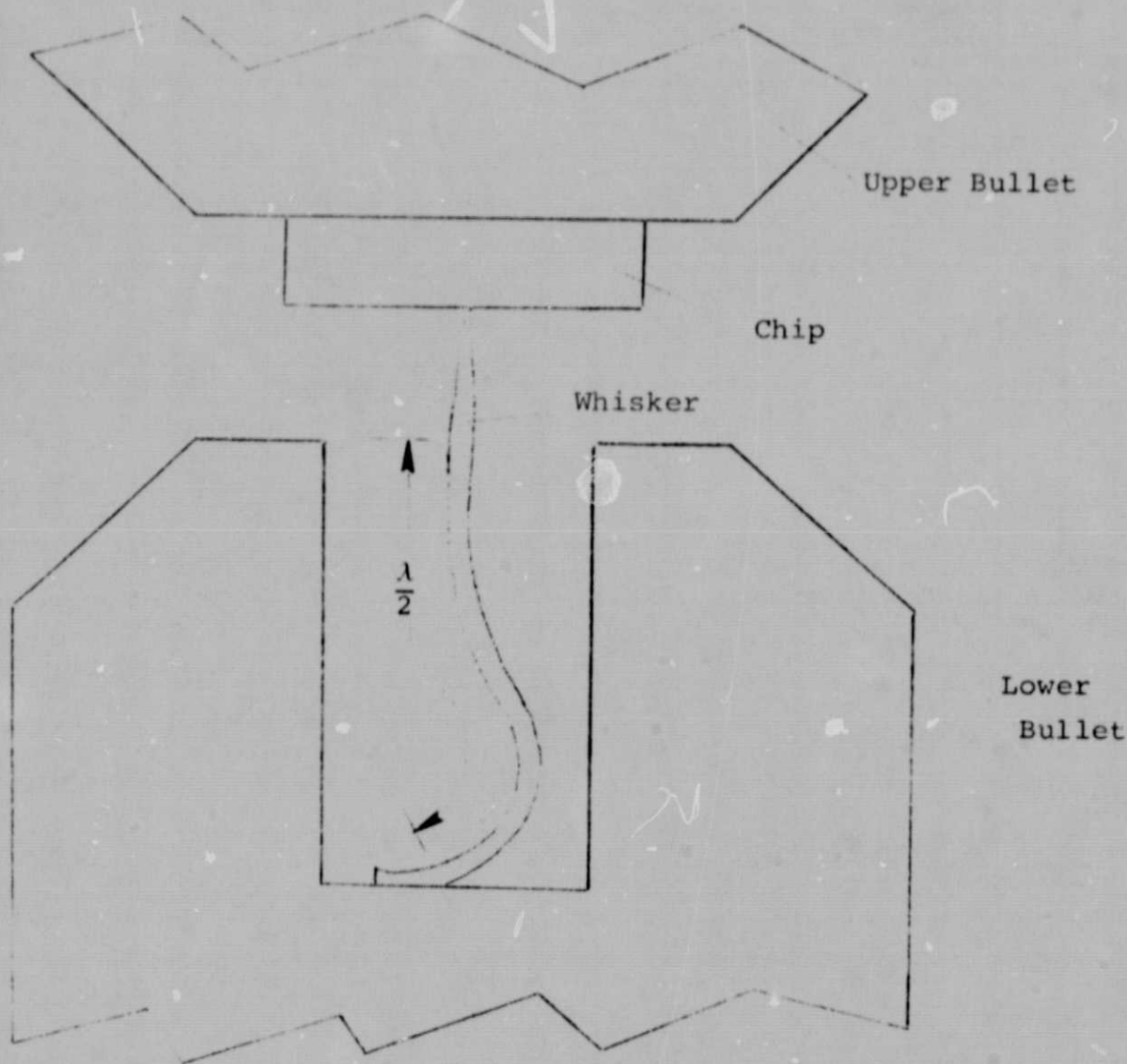
Figure 1. The Improved Flight Mixer

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The two SMA connectors evident in the photo are the I.F. output port and D.C. bias input, respectively. The D.C. blocking section is also built into the mixer as will be discussed. The mixer was flown successfully on a trans-atlantic data flight on the NASA CV 990 and seemed to exhibit the required mechanical stability.

2.1 The Recessed Whisker

One of the major problems associated with the design of a high frequency mixer is the construction of the contacting whisker. The whisker represents an inductance directly in series with the diode device. Since this inductance must be resonated for useful operation of the mixer, it is desirable to keep the whisker length as short as possible. At the same time it is necessary to have the whisker provide pressure to maintain the contact to the diode thus requiring a spring bend in the whisker. At high frequencies it becomes extremely difficult to produce a short spring whisker with reproducible electrical properties due to the limitations associated with bending the .0005 in diameter whisker wire into small radius bends. This difficulty has been overcome by means of recessing the whisker as shown in Fig. 2. The whisker is made with a one-half wavelength length recessed down into a cylindrical hole in the lower bullet. This half wavelength section is a coaxial length of shorted transmission line which then reflects an electrical short circuit at the opening of the recess hole. Thus, the only remaining inductance



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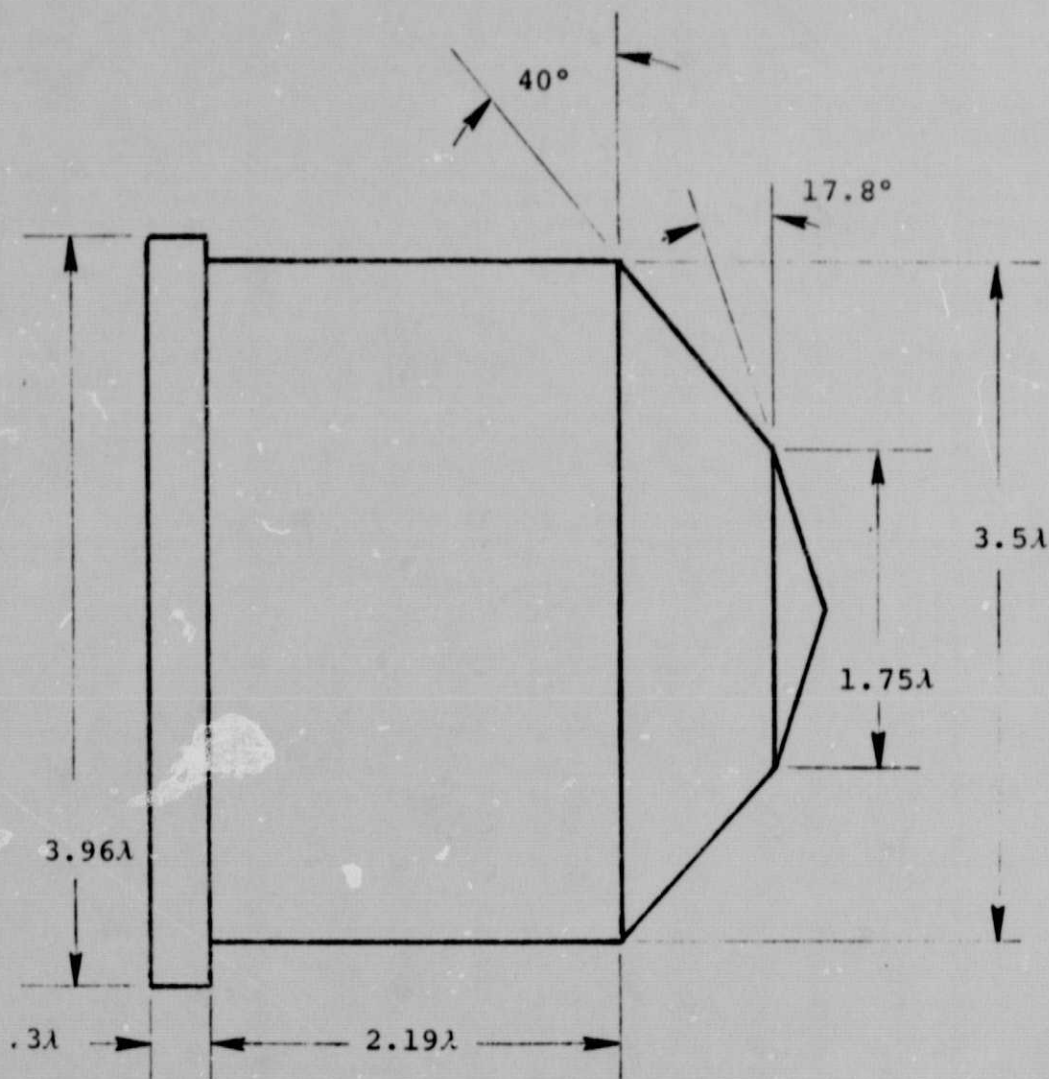
Figure 2. The Recessed Whisker Geometry

In series with the diode is due to the very short straight section of whisker between the chip and the hole. Since the whisker has a considerable length to diameter ratio, a slight bend is easily put into the whisker to provide the required spring tension. The technique should allow reasonable size whiskers to be constructed at frequencies up to about 1 TH. The recessed whiskers have already been successfully tested at frequencies up to 671 GHz (2). The whiskers were found to have very reproducible electrical characteristics.

2.2 Equalization of Mixer Beamwidths

During the initial development of the quasi-optical mixer it was determined that the 3.5 wavelength diameter circular coupling hole produced a radiation pattern for the mixer, which was broader in the E plane than the H plane. Measured data gave an H plane 3db width of 16° and an E plane width of 30° . Since it is desirable to have equal beamwidths for symmetrical illumination of a collimating lens, additional work was undertaken to balance the beamwidths and produce a circularly symmetric pattern.

The improved radiation characteristics of the mixer were obtained by turning a small lens to fit into the coupling hole which can be seen in Fig. 1. The lens was made of teflon and its cross-section is shown in Fig. 3. The lens was pressed into the 3.5 wavelength diameter coupling hole up to the 0.3 wavelength thick lip seen in the Figure. The lens produces two effects. It collimates the energy from the bicone to



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Figure 3. The Beamwidth Equalization Lens

produce a uniform phase front across the hole while at the same time introducing an illumination taper in the E plane. This taper is due to the natural concentrating of energy at the lens center as is usually experienced with a plano-convex lens.

The resulting radiation patterns of the lens corrected mixer are shown in Figs. 4 and 5. The patterns were made at 185 Ghz and some fine structure is seen on the patterns due to range reflections. As can be seen in the figures, good agreement between the E and H plane patterns is observed down past the -10 db points. Both patterns have a 3 db width of about 28° and are quite acceptable for the primary illumination of a collimating lens. No attempts were made to groove the surfaces of the mixer lens to eliminate dielectric-air interface reflections. Typical increases in mixer conversion performance of 0.5 db were measured with the introduction of the lens indicating that the lens was also eliminating some small amount of sidelobe energy which was being spilled out of the quasi-optical mixer system.

2.3 The I.F. Matching Section

It was decided to investigate the possibility of incorporating the I.F. matching section and D.C. bias connection directly into the mixer mount to provide a broader matching bandwidth and increased reliability. From the previous study (1), it was determined that at the 1.4 Ghz I.F. frequency the diode and whisker appear at a lumped impedance

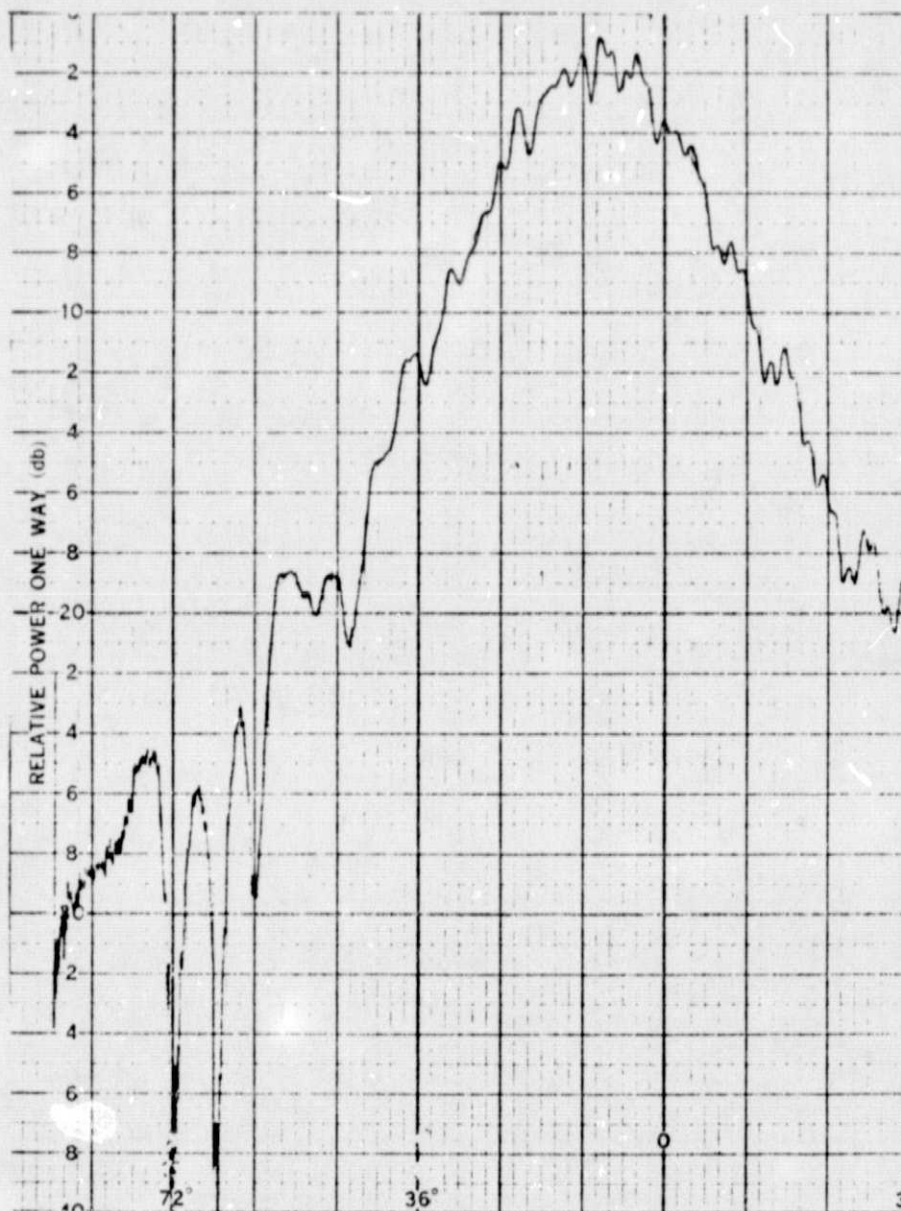


Figure 4. H Plane Pattern of the Lens Corrected Mixer

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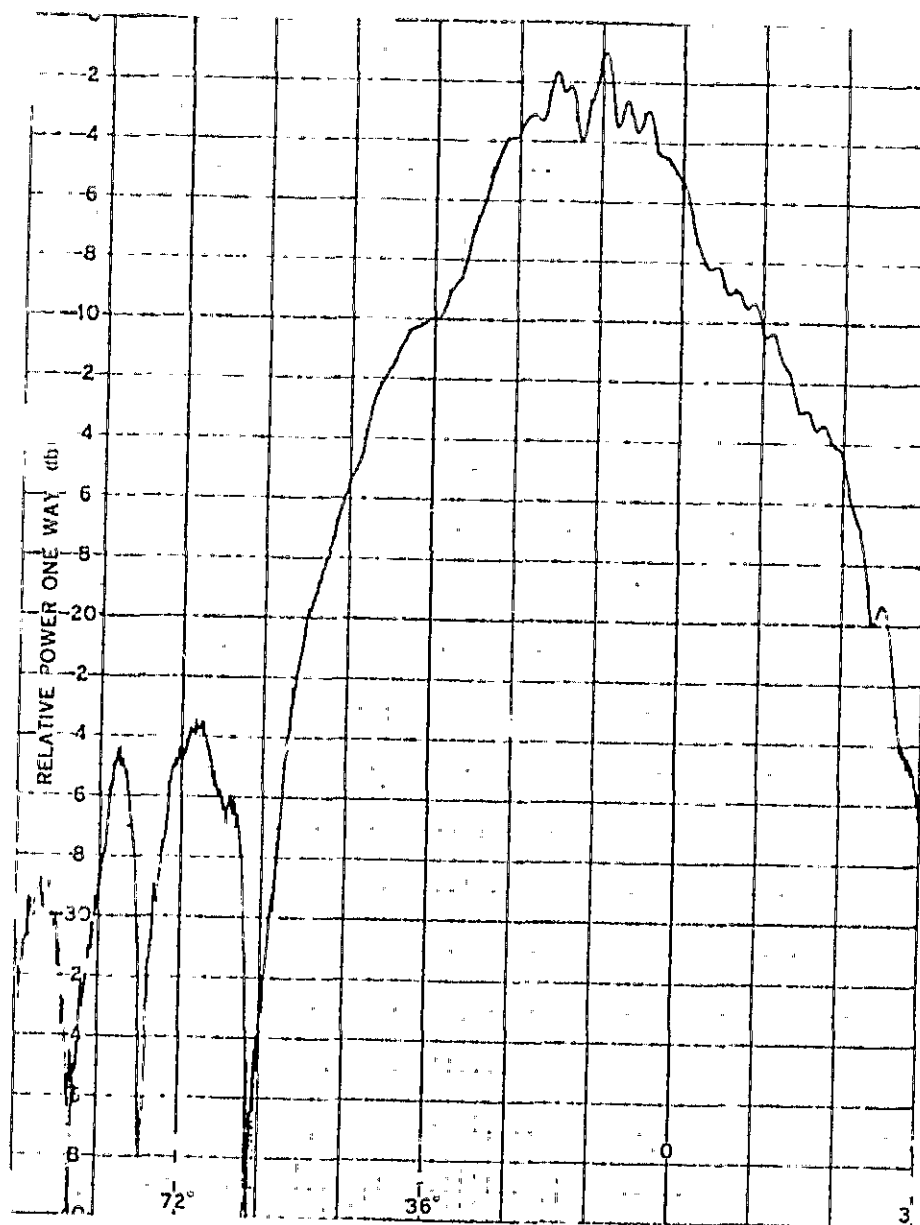
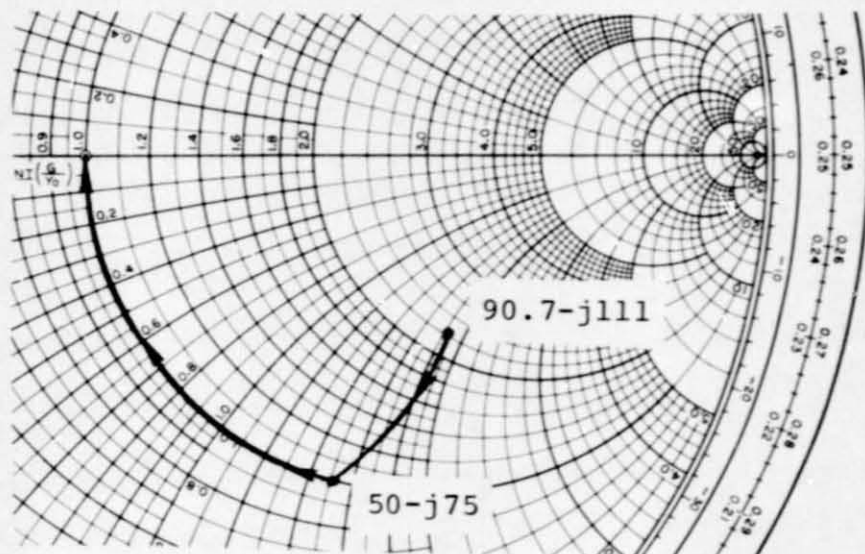
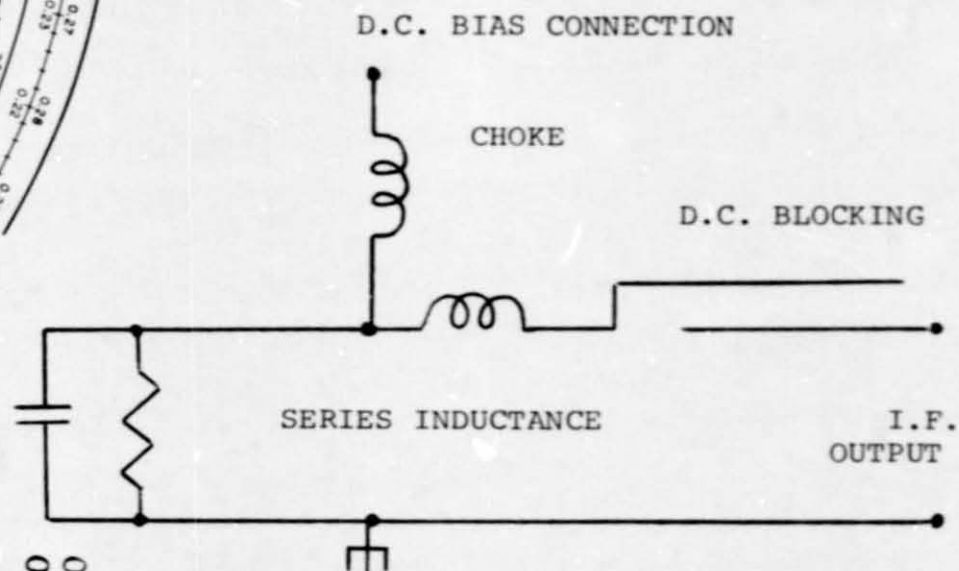


Figure 5. E Plane Pattern of the Lens Corrected Mixer

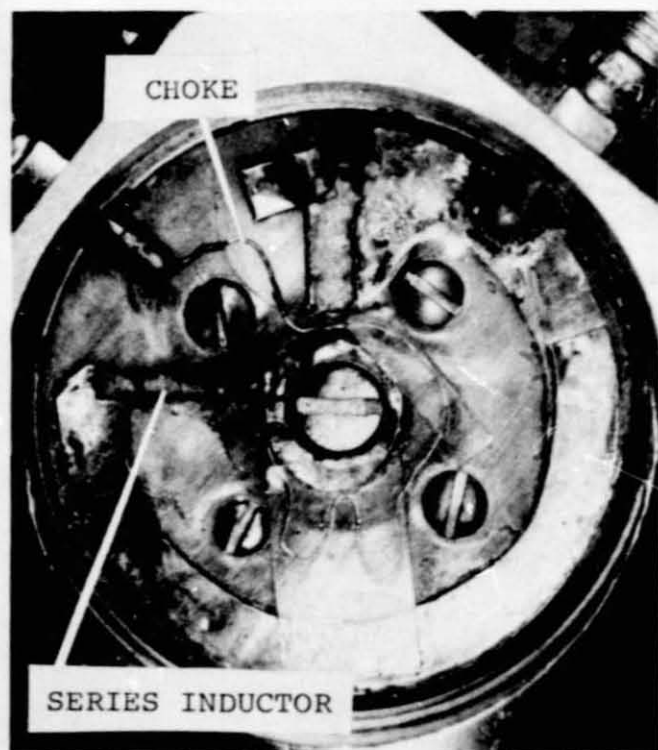
of 90.7 -j1111 ohms at the apex of the 50 ohm biconical line. The matching section which was designed for the mixer can be seen in Fig. 6. The Smith chart of Fig. 6(a) shows how the match is achieved. By moving up to the top of the upper bullet the diode impedance is transformed to the point 50 -j75. A match is then obtained by placing an inductance in series with the line at this point to bring the impedance into the center of the Smith chart along the 50 ohm resistance circle. The complete circuit for the matching section is shown in Fig. 6(b). A D.C. bias connection is made through a high impedance choke section as shown. The series inductor is connected to the 50 ohm OSM I.F. output connector through a D.C. blocking section. Fig. 6(c) shows the actual circuit. The screw head in the center of the photograph connects directly to the top of the upper bullet. The choke section is made of a quarter wave (1.4") length of 0.010" diameter wire which is meandered around so as to fit within the confines of the limited enclosure at the top of the mixer. The series inductor is the narrow strip of foil connecting the screw head to the D.C. block. The block itself is a quarter wave open length of low impedance transmission line. It is formed by covering the circular length of 50 ohm microstrip seen in the Figure with a layer of .005" mylar overlaying the mylar with a second foil conductor. The microstrip is connected to the I.F. output connector and the overlayed foil to the series inductor. The net result is a series low impedance parallel plate quarter wave open line



(a)



(b)



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(c)

Figure 6. The I.F. Matching Section

formed by the microstrip conductor at the bottom, the mylar in the middle and the overlaid foil at the top. A small foil island is also seen to be soldered to the I.F. output connector. The capacitance provided by this island was experimentally found to improve the measured performance of the network.

The input VSWR to the I.F. port of the mixer was measured under normal conditions of applied local oscillator power. The results of these measurements are shown in Table I.

TABLE I

Mixer VSWR as a Function of I.F. Frequency

<u>Frequency (Ghz)</u>	<u>VSWR</u>
1.28	1.90
1.30	1.60
1.32	1.35
1.34	1.18
1.36	1.12
1.38	1.24
1.40	1.45
1.42	1.60
1.44	1.95

It is seen that the VSWR is less than 2:1 over at least a 160 Mhz frequency band.

3.0 ENGINEERING MEASUREMENTS

With the availability of carcinotron oscillators provided by the European Space Research and Technology Centre, a laboratory measurement system was assembled for measurement of Engineering materials at frequencies between 230 and 300 Ghz. In the following sections the results of the measurements of the transmission properties of wire grids and common dielectric materials is presented.

3.1 Wire Grid Evaluation

Wire grids are commonly used in the millimeter and sub-millimeter ranges as polarization filters and reflection elements for beamsplitters and resonators. The grids commonly used at JPL for this purpose are photo-etched strips of .0005" copper supported on a thin .005" teflon substrate as shown in Fig. 7. The transmission properties of grids having a strip width of .0035 were measured for grid periodicities varying from .017 to .009 inches. The measurements were made by inserting the grid materials into a one-inch diameter beam passing from a carcinotron source to a Schottky diode detector via feed horns and collimating lenses. The change in the D.C. bias level of the detector due to the introduction of the grid was then noted and a square law characteristic for the detector assumed. The measurements were made for a beam incidence angle such that the magnetic field of the beam was perpendicular to the strips while the electric field made an angle of 45° to the strips. This configuration was chosen

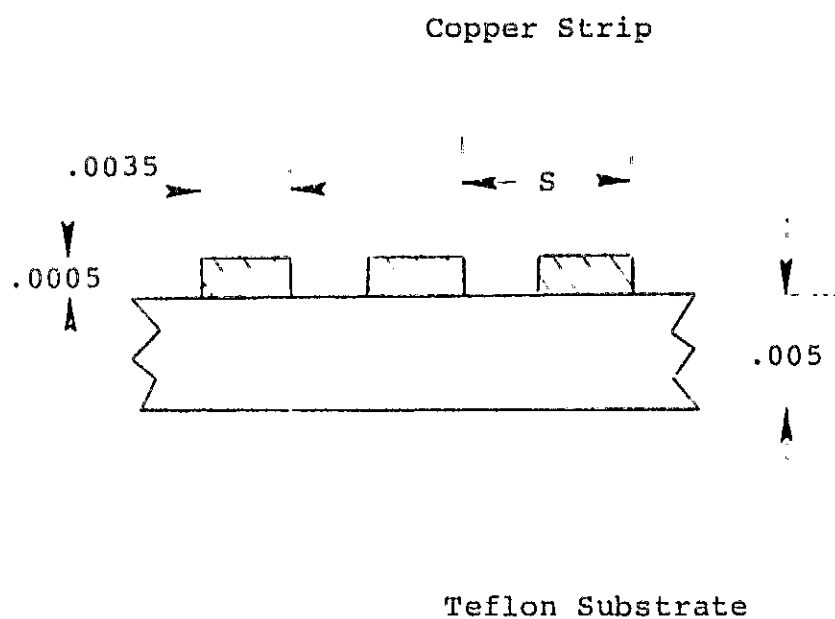


Figure 7. The Photo-Etched Grid Geometry

because the grids are used in this orientation in the quasi-optical local oscillator injection system now in use at JPL. The results of measurements made at the frequencies of 230, 250 and 263 Ghz are given in Table II. It is seen that the transmission is a strong function of the grid periodicity with relatively little change over the limited frequency range of the measurements.

TABLE II

Fractional Power Transmission for Grids of Various Periodicities

Frequency (Ghz)	Grid Periodicity S (inches)			
	S = .017	.015	.012	.009
230	.65	.49	.29	.16
250	.71	.59	.35	.17
263	.64	.50	.28	.16

3.2 Dielectric Materials

The ohmic transmission loss of a number of dielectric materials was measured with a radiometer at 301.6 Ghz. The measurement was performed by recording the total power output of the radiometer first looking into an ambient load and then into a 520°K heated black body to obtain an absolute temperature calibration. A sample of the material typically one inch thick was then inserted between the radiometer and the hot load and

the resulting attenuation noted. Dielectric reflection effects were minimized by holding the material for incidence at the Brewster angle and orienting the sample to produce the best transmission. The results are shown in Table III

TABLE III

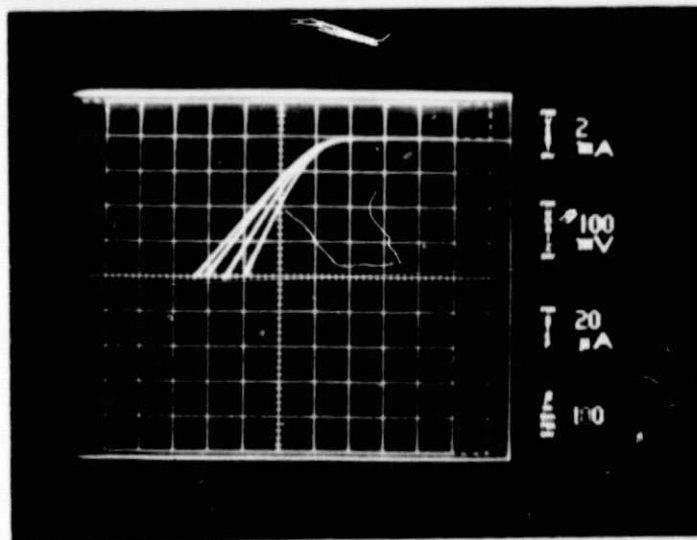
Measured Attenuation of some Common Dielectric Materials at
301.6 Ghz

<u>Material</u>	<u>Attention (db per inch)</u>
Teflon	.68
TPX	.96
Styrafoam	.15
Quartz (fused)	4.25
Plexiglass	19.00
Window glass	Opaque
Lexan	18.00
Delrin	20.00

It is seen that teflon is the best of the materials measured with TPX a close second. Dry Styrafoam was seen to be almost transparent as is usually the case at lower frequencies

4.0 THE BURN IN PHENOMENON

In the course of whiskering the mixer a series resistance anomaly has been repeatedly observed. After a contact has been made at relatively low current (less than one ma.), an unstable V-I characteristic is seen at high currents around ten ma. The slope of the curve is first found to be low, indicating high series resistance for the diode. With application of higher voltage to the diode the curve is observed to increase its slope to a limiting value which is characteristic of the diode. The mechanism associated with this "burn in" of the diode characteristic is at present unknown, and is the subject of an ongoing research program. The phenomenon can be seen in the curve tracings of Fig. 8. Several positions of the V-I curve are shown for repeated camera exposures during the burn in operation. Satisfactory mixer performance has been observed after the burn in indicating the absence of destructive effects during the process. However, frequent attempts at burning in the diode will result in a puncture of the epi-layer due to the high currents involved. When this happens the diode characteristic is seen to become that of a point contact diode.



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Figure 8. Curve Tracings of the Burn in Phenomenon

5.0 CONCLUSIONS AND RECOMMENDATIONS

It has been determined in this study that it is possible to construct a quasi-optical mixer which is stable enough for aircraft flight applications. The recessed whisker technique described in this report provides a method of constructing a whisker geometry that can be scaled with frequency at least up to 1 TH. The elimination of a separate I.F. matching device along with the unreliable external connection directly to the diode mounting bullet has been demonstrated at an I.F. frequency near 1.4 Ghz.

Ohmic dielectric losses in Teflon have been measured at less than 0.7 db/in at 301 Ghz, indicating that the construction of fairly efficient lenses is still possible at these frequencies.

It is recommended that studies be undertaken to determine the cause of the observed "burn in" phenomenon in order to produce more stable and reproducible whisker contacts.

6.0 NEW TECHNOLOGY

No reportable items of new technology have been identified in the work described in this report.

7.0 REFERENCES

1. Gustincic, J.J., "A Millimeter Wave Quasi-optical Mixer and Multiplier," JPL Contract No. 954492, Report No. TR078.
2. Gustincic, J.J., "Extension of Schottky Diode Receivers into the Submillimeter Region," JPL Contract No. 954492, Report No. TR079.